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(54) SYNTHETIC QUARTZ GLASS OPTICAL MEMBER FOR EXCIMER LASER AND PRODUCTION THEREOF

SYNTHETISCHES OPTISCHES ELEMENT AUS QUARZGLAS FÜR EXCIMER-LASER UND SEINE HERSTELLUNG

ELEMENT OPTIQUE EN QUARTZ DE SYNTHESE POUR LASER A EXCIMERE ET REALISATION DE CET ELEMENT

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Description

TECHNICAL FIELD

The present invention relates to a synthetic quartz glass optical member which is very stable against irradiation with ultraviolet laser beams having oscillation wavelengths of not more than 300 nm and a method for producing the same and more specifically to an optical member of synthetic quartz glass which is very stable against irradiation with KrF excimer laser beams and ArF excimer laser beams and a method for producing the same.

The present invention further pertains to a method for producing a quartz glass member suitably used as an optical member such as a window, a mirror, a lense and a prism which constitute an optical system of a lithography device provided with, in particular, an excimer laser as a light source and used for producing semiconductor chips.

BACKGROUND OF THE INVENTION

Along with a recent increase in the degree of integration of LSI's, these has been required a technique which permits display of accurate images, for instance, with minute lines of a width on the order of submicrons in a photolithography technique or a lithography technique for displaying an integrated circuit pattern on a wafer. In the photolithography technique, an attempt has accordingly been done to adopt light rays of short wavelengths as light sources for exposure systems in order to form accurate images, by lines having such a quite narrow width. There is required, for instance, a stepper lense for lithography having excellent transparency to ultraviolet rays, uniform refractive index distribution for ultraviolet rays, in particular, ultraviolet laser beams, and high durability to the irradiation of ultraviolet laser beams in order to display, on a wafer, accurate and clear distortion-free images of integrated circuit patterns by fine lines without light and dark irregularities.

However, lenses made from a conventional optical glass currently used have very low transmittance to ultraviolet rays. For instance, when using ultraviolet rays having wavelengths falling within the wavelength range *shorter* than 365 nm (i-ray), the transmittance to ultraviolet rays is abruptly reduced during operating the optical system and it is thus practically impossible to use such lenses as a stepper lense. In particular, when using ultraviolet rays having wavelengths falling within the wavelength range shorter than 365 nm (i-ray), the lense generates heat through absorption of the irradiated ultraviolet rays. This leads to changes of optical characteristics of the optical lense and in turn becomes a cause of a deviation of the focal length thereof. For this reason, quartz glass has been used as a material for producing parts through which ultraviolet rays are transmitted.

The quartz glass made of a naturally-occurring rock crystal which has a low transmittance to ultraviolet rays having wavelengths of not more than 250 nm absorbs light in the ultraviolet region during irradiation with ultraviolet rays thereby and the ultraviolet transmission rate is further reduced. It has thus been practically impossible to use such quartz glass as a material for producing a stepper lense. It is believed that the quartz glass made of a naturally-occurring rock crystal absorbs light rays in the ultraviolet region due to impurities present in the quartz glass and for this reason, synthetic quartz glass having a low impurity-content, i.e., synthetic silica glass has been used for producing optical members for use in the ultraviolet region.

In order to prevent any contamination with metallic impurities, the presence of which in general becomes a cause of the ultraviolet absorption, the synthetic quartz glass has been prepared by directly introducing, into an oxyhydrogen flame, vapor of a volatile, highly pure silicon compound which is chemically synthesized and purified through distillation, for instance, a silicon halide such as silicon tetrachloride ($SiCl_4$); an alkoxysilane such as ethoxysilane ($Si(OC_2H_5)_4$), methoxysilane ($Si(OCH_3)_4$) or the like; or an alkylalkoxysilane such as methyltrimethoxysilane ($SiCH_3(OCH_3)_3$), ethyltriethoxysilane ($SiC_2H_5(OC_2H_5)_3$) or the like to cause flame-hydrolysis by the action of the oxyhydrogen flame, depositing and melting fine glass particles formed through the decomposition of the compound on a heat-resistant rod-like core material to give a transparent glass material. Alternatively, it is also possible to form a transparent glass material by depositing the foregoing fine glass particles on a heat-resistant rod-like core material to give a porous glass material and then heating and melting the porous glass material in an electric furnace.

The transparent synthetic quartz glass thus produced is quite pure, almost free of metallic impurities and can effectively transmit lights in a short wavelength region on the order of about 190 nm. Therefore, the synthetic quartz glass has been used as a material for transmitting light from ultraviolet lasers, more specifically, excimer lasers such as KrF lasers (248 nm), XeCl lasers (308 nm), XeBr lasers (282 nm), XeF lasers (351, 353 nm) and ArF lasers (193 nm); and 4-fold higher harmonics (250 nm) of YAG lasers in addition to the foregoing i-line.

For instance, an attempt has been made to synthesize highly pure quartz glass having a content of elemental metallic impurities of not more than 0.1 ppm and comprising OH groups in a predetermined concentration by improving the purity of silicon tetrachloride as a starting material and controlling the conditions for flame-hydrolysis by an oxyhydrogen flame and to thus produce quartz glass parts for optical use having improved durability to light from ultraviolet lasers (JP-A-1-167258).

Although the quartz glass parts for optical use prepared according to these methods exhibit excellent durability to light from ultraviolet lasers, the production thereof requires an increase of the production process-

es. Therefore, they suffer from various problems from the viewpoint of production techniques and production time as well as from the economical standpoint.

Incidentally, the synthetic quartz glass likewise begins to absorb ultraviolet rays in a certain region upon irradiation with ultraviolet rays. This "new" absorption band within the ultraviolet region which is absorbed by the synthetic quartz glass is apparently due to the presence of structures formed from components of the quartz glass other than SiO_2 such as SiOH or SiCl, or intrinsic defects due to oxygen excess- or deficient-structures such as Si-Si and Si-O-O-Si, which possibly generate paramagnetic defects through optical reactions. There have been detected and identified, by ESR spectrometry or the like, various paramagnetic defects in the synthetic quartz glass which become a cause of light absorption, for instance, E' center (Si) and NBOHC (Si-O ·).

As has been explained above, the paramagnetic defects in general have optical absorption bands. For instance, absorptions at E' center, 215 nm, and at 260 nm (which has not yet been correctly identified) are known as examples of such absorption bands due to the paramagnetic defects in quartz glass falling within the ultraviolet region, which are observed upon irradiation with ultraviolet rays. These absorption bands are relatively broad and strong and, therefore, this becomes a serious problem when it is used as a material for transmitting lasers such as ArF lasers (193 nm) and KrF lasers (248 nm).

For the foregoing reasons, the synthetic quartz glass used for excimer lasers must have high durability to ultraviolet rays such that it does not cause any new absorption band even when it is irradiated with strong ultraviolet rays such as light rays from ultraviolet lasers.

An object of the present invention is to provide an optical quartz glass optical member for use in an optical system provided with an ultraviolet laser namely a excimer laser, as a light source, to provide a solution to the problem of the reduction in the transmission rate of a quartz glass optical member when irradiated with ultraviolet rays.

DISCLOSURE OF THE INVENTION

The inventors of this invention have conducted intensive studies to solve the foregoing problem, have found that hydroxyl groups (OH groups) and chlorine atoms serve as impurities which are linked to intrinsic defects present in the synthetic quartz glass and that quartz glass having excellent resistance to excimer laser rays can be obtained by reducing the OH group-content of the synthetic quartz glass to 10 to 200 ppm, reducing the chlorine-content ranging from 20 to 100 ppm and designing the quartz glass so as to have uniform refractive index distribution on order of not more than 1 x 10^{-6} as expressed in terms of Δn and a birefringence of not more than 5 nm/cm.

According to the present invention, there is thus provided synthetic quartz glass used as a material for producing optical members for excimer lasers, which allows suppression of reduction in the ultraviolet transmission rate upon irradiation with light from excimer lasers as much as possible as well as a method for producing the same. More particularly, the present invention provides an optical quartz glass optical member suitably used for producing a stepper lense for excimer lasers and a method for the preparation thereof.

According to a first aspect of the present invention there is provided an optical member for excimer lasers made from synthetic quartz glass wherein said optical member has an OH group-content ranging from 10 to 200 ppm, a chlorine-content ranging from 20 to 100 ppm, a hydrogen molecule-content of not more than 1 X 10^{16} molecules/cm^3, a uniformity of refractive index distribution Δn of not more than 1 X 10^{-6} wherein Δn is defined as the difference of refractive index in a light-transmissive plane of said optical member between the maximum and minimum refractive indices, a birefringence of not more than 5 nm/cm and an internal transmittance as determined at 245 nm of not less than 99%.

According to a second aspect of the invention there is provided a method for producing an optical member for excimer lasers made from synthetic quartz glass wherein said optical member has an OH group-content ranging 10 to 200 ppm, a chlorine content ranging from 20 to 100 ppm, a hydrogen molecule-content of not more than 1 X 10^{16} molecules/cm^3, a uniformity of refractive index distribution Δn of not more than 1 X 10^{-6} wherein Δn is defined as the difference of refractive index in a light-transmissive plane of said optical member between the maximum and minimum refractive indices, a birefringence of not more than 5 nm/cm and an internal transmittance as determined at 245 nm of not less than 99% comprising the steps of:

flame-hydrolyzing a volatile silicon compound using an oxyhydrogen flame to form fine silica particles;
depositing the fine silica particles on a heat-resistant substrate to give a porous silica ingot;
dehydrating and degassifying by heating the porous silica ingot at a temperature of not less than 1400°C and a high degree of vacuum on the order of not less than 1 X 10^{-2} Torr, wherein said dehydrating and degassifying steps occur either sequentially or simultaneously;
uniformizing the dehydrated and degassified transparent quartz glass to give highly uniform quartz glass free of stria in at least on direction thereof;
molding the resulting highly uniform quartz glass; and annealing the molded quartz glass article.

The inventors of this invention have found out that if the internal light transmittance (as determined at 245 nm) of the synthetic quartz glass from which the foregoing optical member is produced is not less than 99%,

the stability of the synthetic quartz glass against the lights from excimer lasers is further improved It is generally believed that the absorption band at 245 nm is an absorption due to oxygen-deficiency. The inventors of this invention have found out that optical material free of this absorption is preferably used for the production of optical members for excimer lasers.

The inventors of this invention have found out that the lower the OH group-content and chlorine-content in the synthetic quartz glass (for instance, not more than 5 ppm for both contents), the higher the durability thereof to the lights from excimer lasers. With regard to, in particular, the content of OH groups which are involved in the light absorption due to the intrinsic defects, it has been found that the synthetic quartz glass having the OH group-content ranging from 10 to 200 ppm ensures acceptable durability to the lights from excimer lasers. However, the OH group-content preferably ranges from 10 to 100 ppm in order to obtain more stable optical members for the excimer lasers which do not exhibit light absorption due to intrinsic defects even if they are operated over a long time period and which ensure good uniformity of refractive index and good birefringence over a long time.

In the present invention, the hydrogen molecule-content of the synthetic quartz glass optical member is limited to not more than 1×10^{16} molecules/cm^3. The limitation of the hydrogen molecule-content to not more than 1×10^{16} molecules/cm^3 ensures the suppression of any reduction of light transmittance in the ultraviolet region possibly observed when an increase in the pulse numbers of the irradiated light from an excimer laser exceeds 1×10^5 pulses at 500 mJ.

It has generally been required for the optical members used in lithography apparatus for semiconductors to have severe uniformity in order to ensure uniform exposure and to prevent any scattering of the resistance to the lights from excimer lasers. However, the inventors have found out that the resistance to excimer laser rays of the optical member can be regarded as being uniform, if the refractive index distribution determined at the light-transmitting plane of the synthetic quartz glass optical member is not more than 5×10^{-6} as expressed in terms of refractive index difference Δn between the maximum and minimum refractive indices thereof. In other words, if the value of Δn is not more than 5×10^{-6}, OH groups and chlorine atoms which are adversely affect the stability of the synthetic quartz glass optical member against ultraviolet rays are approximately uniformly distributed throughout the part and thus the optical member ensures uniform and overall durability to the lights from excimer lasers. Moreover, the foregoing uniform refractive index distribution is favorable for optical members such as lenses.

According to the invention the refractive index distribution An is even much lower, namely not more than 1×10^{-6}.

As materials for synthetic quartz glass used in the production of synthetic quartz glass optical members for excimer lasers, usable in the present invention, thereby may be used, for instance, volatile silicon compounds such as alkylpolyalkoxysilanes or alkoxysilanes (e.g., methyltrimethoxysilane [$Si(CH_3)(OCH_3)_3$] and tetramethoxysilane [$Si(OCH_3)_4$]); or other silane compounds; or volatile inorganic silicon compounds (e.g., silicon tetrachloride).

According to the second aspect of the present invention, a volatile silicon compound is vaporized and hydrolyzed through the direct flame-hydrolyzation technique to give fine particles of silica glass, followed by deposition of the silica glass on a heat-resistant substrate to form a rod-like porous ingot of synthetic silica glass, so-called "soot".

The porous synthetic silica glass ingot can be produced according to, for instance, the vapor-phase axial deposition technique (VAD method) and the outside vapor deposition technique (outside CVD method). However, the present invention is not restricted to these specific methods since it is sufficient that the porous synthetic silica glass ingot used in the invention is a porous bulk material of synthetic silica glass.

The porous synthetic silica glass ingot comprises OH groups formed through the oxyhydrogen flame treatment must be removed in order to prevent the formation of intrinsic defects due to the presence of these OH groups.

With regard to glass for the production of optical fibers, the reduction of OH groups in the glass to a level as low as possible is conventionally carried out by heat-treating the glass in a chlorine gas atmosphere (chlorine gas, Cl_2, serves as a dehydrating agent) during the step for synthesis of porous silica glass or the step for vitrification into transparent glass. This method permits the reduction of the OH group-content in the glass, but chlorine gas remains in the resulting glass and this accordingly becomes a cause of the formation of intrinsic defects in the glass. Alternatively, the glass may be heat-treated in an inert gas, but the inert gas is dissolved in the glass so far as the treatment is carried out at ordinary pressure. This likewise becomes a cause of intrinsic defects.

On the other hand, the porous silica glass ingot comprises, in addition to OH groups, a substantial amount of hydrogen molecules which originate from the oxyhydrogen flame treatment used for the production of silica ingot in the form of a solid solution. With respect to the so-called residual hydrogen molecules remaining in this silica glass ingot in the form of a solid solution, it had been found that the presence of the residual hydrogen molecules in the silica glass ingot, which is produced by the direct synthetic method, in the form of a solid solution serves to suppress any absorption of light falling within the ultraviolet region if the concentration of hydrogen molecules dissolved is not less than 5×10^{16} molecules/cm^3 (U.S.-A-5,086,352).

On the other hand, if the residual hydrogen mole-

cules remain in the silica glass ingot in the form of a solid solution having a concentration of not more that 5×10^{16} molecules/cm^3, there is not observed any inhibiting effect on the occurrence of absorption bands within the ultraviolet region. Rather it has been found that the occurrence of absorption bands within the ultraviolet region may even increase.

Nevertheless, the inventors of the present invention have found out that the occurrence of absorption bands within the ultraviolet region can be suppressed if the residual hydrogen molecules remain the silica glass ingot in the form of a solid solution having a concentration of not more that 1×10^{16} molecules/cm^3.

Thus, according to the second aspect of the present invention, the foregoing synthetic silica glass is vitrified by heating it in an atmosphere maintained at a degree of vacuum of not less than 1×10^{-2} Torr, i.e., at a pressure of not more than 1×10^{-2} Torr and at a temperature ranging from, not less than 1400°C. The degree of vacuum and temperature for the vitrification of the synthetic silica glass into transparent glass are selected such that the OH groups and metallic impurities present in the synthetic silica glass are removed through volatilization and in particular, the heating temperature is preferably selected such that it not less than 1400°C but as low as possible, depending on the size of the porous ingot to be treated and the transparent-vitrification time.

The vitrification of the foregoing porous ingot of synthetic silica glass is caused through a dehydration-condensation reaction of silanol groups (SiOH) represented by the following reaction scheme:

$$2SiOH \rightarrow SiOSi + H_2O$$

The water molecules formed through the dehydration-condensation reaction of silanol groups diffuse from inside to outside through interstices between fine silica glass particles and are thus finally discharged out of the system. Therefore, the vitrification of the synthetic glass ingot into transparent glass must be performed during diffusion of the resulting water molecules through the interstices between the fine glass particles in order to remove OH groups.

Therefore, if the vitrification temperature exceeds 1700°C during the reaction, the sintering reaction of the silica fine particles rapidly proceeds on the silica glass surface prior to substantial completion of the dehydration-condensation reaction. This results in the premature vitrification of the porous silica glass ingot into transparent glass and in turn OH groups are not removed but remain in the synthetic quartz glass.

On the other hand, the dehydration-condensation reaction of silanol groups proceeds at a temperature lower than the sintering temperature, for instance, about 800°C. For this reason, when OH groups are removed from the synthetic quartz glass, the dehydration-condensation reaction of silanol groups is completed prior to the completion of the sintering of the fine particles of silica glasses so that the OH groups are removed through diffusion.

Thus, the removal of OH groups from the quartz glass is preferably carried out through two-stage vitrification of the porous silica glass ingot into transparent glass, which comprises maintaining the ingot at a temperature ranging from, for instance, 800 to 1200°C over a predetermined time for promoting the dehydration-condensation reaction of silanol groups and then sintering the fine particles of silica glass to give transparent glass ingot.

Alternatively, the vitrification of the synthetic silica glass into transparent glass is performed by the zone melting method, the vitrification must be carried out under conditions such that the dehydration-condensation reaction of silanol groups is promoted as gently as possible. More specifically, the vitrification must be carried out while moving the ingot within a heating zone as slow as possible or the vitrification must be performed at a temperature as low as possible.

In general, it is preferred to decrease the traveling speed of the ingot within the heating zone as the size thereof increases.

It has been found that the vitrification treatment should be performed within an atmosphere maintained at a high degree of vacuum on the order of not less than 10^{-2} Torr to externally release, through diffusion, the water (H_2O) generated through the dehydration-condensation reaction of silanol groups during the vitrification as soon as possible. It is herein important that the dehydration-condensation reaction of silanol groups and the vitrification of the porous silica glass ingot into transparent glass should be carried out at a high degree of vacuum on the order of not less than 10^{-2} Torr, i.e., at a pressure of not more than 10^{-2} Torr. In this respect, if the porous ingot of silica glass to be treated has a large size, the amount of H_2O generated is correspondingly increased to a substantial extent. Thus, it is effective to use a vacuum-exhaust device having a high evacuation speed rather than that having a high ultimate vacuum.

The synthetic quartz glass thus produced has a low OH group-content and more specifically the quartz glass has an OH group-content of not more than 50 ppm, preferably not more than 30 ppm and further the glass comprises quite small amount of metallic impurities. Thus, the quartz glass is transparent highly pure quartz glass.

The quartz glass produced by the CVD method comprises a heat-resistant substrate and a layer of silica glass fine particles deposited thereon and the deposit of the silica fine particles has a scattering of density due to temperature changes during the production thereof. The scattering of density becomes a cause of the formation of striae after the vitrification. Thus, the transparent quartz glass produced by the CVD method in general has a stria.

However, this stria must be removed if the transparent quartz glass produced by the CVD method is used

for the production of optical members such as a stepper lense. In the present invention, the foregoing highly pure transparent quartz glass should be treated according to the method as disclosed in, for instance, U.S. -A- Nos. 2,904,713; US-A-3,128,166; US-A-3,128,169 and U.S.-A-3,485,613, to remove the striae.

For instance, there has been known a method for removing such striae which comprises fitting a rod-like transparent synthetic quartz glass ingot having a stria to a turning machine, locally heating the quartz glass ingot with a burner or in an electric heater to a temperature of at least the softening point thereof and rotating the turning machine to give a twist to the rod-like transparent synthetic quartz glass ingot till the stria disappears.

According to this method, the removal of the striae is carried out by moving in order the rod-like synthetic quartz glass ingot along the heating means and ultimately the entire rod-like synthetic quartz glass ingot is homogenized. The temperature during the removal of the striae must be not less than the softening point of the quartz glass, for instance, not less than 1600°C. The moving speed of the synthetic quarts glass ingot along the heating means or the like are of course selected appropriately, depending on the shape and weight of the quartz glass optical member to be treated.

The transparent synthetic quartz glass from which the stria is removed is then formed into a final article having a shape and size suitable for use as, for instance, a stepper lense. The molding is generally carried out by introducing the transparent synthetic quartz glass material from which the stria is removed into a crucible having a proper shape, heating it in a heating furnace to a temperature of at least 1500°C. At this stage, the quartz glass material deforms under its own weight. In this case, a crucible made of carbon can generally be used as in conventional methods. In addition, a heating furnace may likewise be used and is made from carbon as in conventional methods. For this reason, the molding is carried out in a vacuum or in an atmosphere of an inert gas such as He or N_2. The conditions for molding such as heating temperature and heating time are properly selected depending on the size and shape of the desired article to be formed.

In general, optical materials must have a strain of not more than 5 nm/cm. Therefore, the molded transparent synthetic quartz glass is subjected to annealing to eliminate the molding strain. The removal of the molding strain is performed by heating the molded transparent synthetic quartz glass to a temperature higher than the strain point of the quartz glass and then by gradually cooling the molded transparent synthetic quartz glass.

In general, the strain point of the quartz glass is about 1025°C. The molded transparent synthetic quartz glass is heated to a temperature ranging from 1100 to 1250°C and then gradually cooled to almost completely eliminate the molding strain. The cooling (annealing) is preferably carried out as slow as possible. This annealing treatment also serves to uniformize the refractive index distribution within the synthetic quartz glass.

The refractive index distribution in the synthetic quartz glass is mainly determined on the basis of the content of impurities such as OH groups and chlorine and the fictive temperature. The number of OH groups in the optical member of the synthetic quartz, glass can be neglected if the content thereof is not more than 10 ppm and other impurities can substantially be neglected in case of the optical member of the synthetic quartz glass according to the present invention. Therefore, the establishment of the fictive temperature during the annealing treatment is very important. More specifically, the fictive temperature should be uniform throughout the molded synthetic quartz glass to be treated, i.e., the molded article of the synthetic quartz glass in order to ensure uniform refractive index distribution in the article. To this end, the molded article of the synthetic quartz glass is heated once to a temperature higher than the annealing temperature, which is followed by maintaining the article at that temperature over a predetermined time period to establish uniform temperature distribution within the article and then substantially slowly reducing the temperature thereof. This is required for preventing the occurrence of temperature difference throughout the molded article of the quartz glass. In this case, the use of a high rate of the temperature reduction arises temperature difference throughout the molded article, this in turn results in the establishment of different fictive temperatures and any uniform refractive index distribution cannot be ensured.

The heating temperature during the foregoing annealing treatment is about 1200°C and the heating time and the temperature reduction rate are appropriately selected while taking into consideration the size and shape of the molded article of the synthetic quartz glass to be annealed. In general, it is preferred to increase the heating temperature and to reduce the temperature reduction rate as the size of the molded article increases.

The optical member of the synthetic quartz glass may have an OH group-content of 10 to 100 ppm and a chlorine-content of not more than 200 ppm. Thus, the total quantity of paramagnetic defects generated through the irradiation with ultraviolet rays can be reduced and the optical member can ensure stable optical properties over a long time period under irradiation with light from excimer lasers.

Moreover, the optical member of the synthetic quartz glass for excimer lasers has a refractive index distribution (Δn) of not more than 5×10^{-6} and more particularly of not more than 1×10^{-6}, as determined on the light transmitting-plane thereof and, therefore, the part has stability against the light from excimer lasers which is uniform throughout the optical member even under the irradiation with the lights from the excimer lasers.

An optical member made from synthetic quartz glass is thus produced by a method which comprises the steps of flame-hydrolyzing a volatile silicon com-

pound using an oxyhydrogen flame to form fine silica particles, depositing the fine synthetic silica particles on a heat-resistant substrate to give a porous ingot of the synthetic silica glass, heating the porous ingot of the synthetic silica glass at a high degree of vacuum on the order of not less than 1 x 10^{-2} Torr to thus vitrify the ingot into a transparent synthetic quartz glass material, then homogenizing the transparent synthetic quartz glass to give highly uniform quartz glass free of stria in at least one direction, preferably three directions thereof, molding the resulting highly uniform synthetic quartz glass and annealing the molded quartz glass article. Therefore, the resulting optical member of the synthetic quartz glass has only a small number of intrinsic defects which become a cause of paramagnetic defects generated through irradiation with ultraviolet rays, for instance, intrinsic defects formed due to other impurities such as SiOH and chlorine and as a result, the occurrence of the paramagnetic defects is suppressed.

As has been discussed above, the quartz glass material for excimer lasers produced according to the present invention has good uniformity and excellent resistance to light from excimer lasers. Therefore, it is suitable for use as, in particular, quartz glass for stepper lenses provided with an excimer laser as a light source. Moreover, the optical member of the invention makes it possible to prevent an increase in absorption within the ultraviolet region observed when irradiating it with ultraviolet rays.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph showing a transmittance curve in the ultraviolet region observed for a sample (having a thickness of 10 mm) of the synthetic quartz glass molded article for optical windows produced in Example 1 of the present invention;

FIG. 2 is a graph showing changes of absorbance at a wavelength of 248 nm observed for the synthetic quartz glass molded articles for optical windows produced in Example 1 of the present invention and Comparative Example 1 respectively;

FIG. 3 is a diaqram showing interference fringes which reflect the refractive index distribution observed for the synthetic quartz glass molded article for optical windows produced in Example 3;

FIG. 4 is a graph showing changes of absorbance at a wavelength of 248 nm observed for the central and peripheral portions of the synthetic quartz glass molded article for optical windows produced in Example 3;

FIG. 5 is a graph showing a transmittance curve in the ultraviolet region observed for a sample (having a thickness of 1.0 cm) of the synthetic quartz glass molded article for optical windows produced in comparative Example 2;

FIG. 6 is a graph showing changes of absorbance at a wavelength of 248 nm observed for the synthetic quartz glass molded articles for optical windows produced in Example 1 of the present invention and comparative Example 2 respectively; and

FIG. 7 is a graph showing absorption curves at 193 nm as a function of irradiated pulse numbers of an ArF laser observed in Examples 4 and 5 of the present invention and Comparative Examples 3 and 4.

The embodiments of the present invention will hereinafter be explained with reference to the following Examples, but the present invention is not limited by the following description and Examples at all.

Example 1

A porous synthetic silica deposit (1 Kg) was produced by introducing silicon tetrachloride into an oxyhydrogen flame to form fine silica particles through flame-hydrolysis of the silicon tetrachloride and depositing the resulting fine silica particles on a rotating target. The resulting porous synthetic silica deposit was introduced into an atmospheric furnace, heated up to 800°C, heat-treated for 10 hours while maintaining at that temperature and introducing a 1:1:8 gas mixture of chlorine, oxygen and nitrogen at a flow rate of 10 l/min, followed by withdrawing the porous synthetic silica from the furnace, then introducing it into a vacuum furnace, raising the temperature to 1600°C at a vacuum of 1 x 10^{-2} Torr, maintaining it at that temperature over 1 hour and cooling it to give a transparent rod-like synthetic quartz glass material.

The synthetic quartz glass material was then uniformized by fitting both ends of the glass material to a turning machine and heating it to a temperature of not less than the softening point thereof with a propane gas burner while rotating the turning machine. The uniformized synthetic quartz glass material was placed in a graphite mold, heated at 1700°C in a nitrogen gas atmosphere to mold it and then annealed in the air. The annealing was performed by maintaining the molded article at 1100°C for 20 hours and then slowly cooling down to 600°C at a temperature reduction rate of 0.5°C/min. After cutting a sample, for the subsequent analysis, from the resulting synthetic quartz glass molded article, the outer periphery thereof was ground and the edge thereof was subjected to mirror polishing to thus give a synthetic quartz molded article for optical window having an outer diameter of 80 mm and a thickness of 20 mm.

The OH group-content of the resulting synthetic quartz glass molded article for the optical window of excimer lasers was determined by infrared spectrophotometric analysis and was found to be 20 ppm. In addition, the concentration of the residual hydrogen molecules was determined by the Raman scattering method and was found to be not more than 1 x 10^{16} molecules/cm^3. Moreover, the ultraviolet transmittance of the synthetic

quartz glass molded article for optical window was determined by ultraviolet spectrophotometer and as a result, no absorption at 245 nm was observed and the internal transmittance thereof was found to be not less than 99%. The transmittance curve observed for the synthetic quartz glass molded article for optical window according to Example 1 is shown in FIG. 1. The internal transmittance is defined to be a value obtained by subtracting a loss due to reflection by the sample from the transmittance shown in FIG. 1 and then reducing the resulting transmittance to that for the sample having a thickness of 1 cm.

Moreover, the chlorine-content of the sample was determined by decomposing the sample for analysis with hydrofluoric acid and then subjecting the decomposed product to silver nitrate-nephelometric analysis and was found to be 100 ppm.

Further, the refractive index distribution of the synthetic quartz glass molded article for optical window was determined using a Fizeau interferometer and lights from an HeNe laser according to the oil-on-plate method and found to be 1 x 10^{-6} as expressed in terms of Δn and the birefringence was found to be 2 nm. The synthetic quartz glass molded article for optical window was irradiated with the light rays from a KrF excimer laser at a fluence of 500 mJ/cm^{2}p, 100 Hz to determine the changes of absorption in the ultraviolet region. The results thus obtained are shown in FIG. 2. FIG. 2 shows changes in shot numbers of absorbance (-log(internal absorption)) with time at a wavelength of 215 nm, which is the wavelength of light absorbed by E' center.

The synthetic quartz glass molded article for optical window has properties suitable for use as an optical member since it has a small change in the absorbance observed upon irradiation with the light from an excimer laser as compared with that observed in Comparative Example 1 as will be described below.

In this Example, the concentration of the residual hydrogen molecules present in the synthetic quartz glass was determined by the Raman scattering method (Zhurnal Prikladnoi Spektroskopii, vol. 46, No. 6, pp. 987-991, June 1987). According to this method, the concentration of the residual hydrogen molecules present in the synthetic quartz glass is determined on the basis of the ratio of the intensity of the Raman band at a wave number of 800 cm^{-1} ascribed to SiO_2 to the intensity of the band at 4135 cm^{-1} ascribed to the hydrogen molecules present in the synthetic quartz glass and the concentration C of hydrogen molecules can be calculated from the following equation (1):

$$C = kI_{4135}/I_{800} \qquad (1)$$

(In Equation (1), I_{4135} is the area intensity of the Raman band at 4135 cm^{-1}, I_{800} is the area intensity of the Raman band at 800 cm^{-1}, k is a constant and equal to 1.22 x 10^{21})

The hydrogen molecule concentration as determined by this equation is expressed in terms of the number of hydrogen molecules per unit volume of 1 cm^3.

The apparatus used in the present invention for the determination of the hydrogen molecule concentration is a Raman scattering spectrophotometer NR-1100 double Monochro Type available from Nippon Bunko Co., Ltd., the detector used is a photomultiplier R943-02 available from Hamamatsu Photonics Co., Ltd. and the laser used is an Ar ion laser (488 nm).

Example 2

A porous synthetic silica deposit produced in the same manner used in Example 1 was heat-treated in an atmospheric furnace maintained at 800°C for 10 hours while supplying a 1:2:7 mixed gas of chlorine, oxygen and nitrogen at a flow rate of 10 l/min, followed by withdrawing the porous synthetic silica, introducing it into a vacuum furnace in which it was heated to 1600°C at a vacuum of 1 x 10^{-2} Torr for one hour and then cooling to give a transparent rod-like synthetic quartz glass material. The resulting synthetic quartz glass material was molded and annealed in the same manner used in Example 1 to give a sample for analysis and a synthetic quartz glass molded article for an optical window of excimer lasers having an outer diameter of 80 mm and a thickness of 20 mm.

The resulting synthetic quartz glass molded article for an optical window of excimer lasers had an OH group-content of 90 ppm and a chlorine-content of 20 ppm. In addition, the synthetic quartz glass molded article for an optical window had an internal transmittance as determined at 245 nm of not less than 99%. The synthetic quartz glass molded article for an optical window was irradiated with the lights from a KrF laser to determine the changes in absorbance at 248 nm under the same conditions used in Example 1 and the results identical to those observed in Example 1 were obtained. This indicates that the synthetic quartz glass molded article has good stability to the laser rays.

Example 3 (comparative)

A transparent synthetic quartz glass produced in the same manner used in Example 1 was treated in the same manner used in Example 1 except that the time for uniformizing was reduced to half to give a sample for analysis and a synthetic quartz glass molded article for an optical window having an outer diameter of 80 mm and a thickness of 20 mm. The resulting synthetic quartz glass molded article for an optical window of excimer lasers had an OH group-content of 90 ppm and a chlorine-content of 20 ppm. In addition, the synthetic quartz glass molded article for an optical window also had an internal transmittance as determined at 245 nm of not less than 99% and the birefringence thereof was 2 nm.

The refractive index distribution of the synthetic quartz glass molded article for optical window was found to be 5 x 10^{-6} as expressed in terms of Δn. The interference fringes which reflect the refractive index distribution of the article is shown in FIG. 3. Samples each having a size of 10 mm x 10 mm x 40 mm were cut from the central portion and the peripheral portion of the synthetic quartz glass molded article for optical windows, respectively and each sample was irradiated with the light from a KrF laser under the same conditions used in Example 1 to determine the changes in absorbance at 248 nm. The results obtained are shown in FIG. 4. Both the central and peripheral portions showed good stability and identical absorbance changes. This indicates that the molded article has uniformity sufficient for use as an optical member.

Comparative Example 1

A porous synthetic silica deposit produced in the same manner used in Example 1 was directly introduced into a vacuum furnace in which it was heated to 1600°C at a vacuum of 1 x 10^{-2} for one hour and then cooling to give a transparent rod-like synthetic quartz glass material. The resulting synthetic quartz glass material was treated in the same manner used in Example 1 to give a sample for analysis and a synthetic quartz glass molded article for an optical window of excimer lasers having an outer diameter of 80 mm and a thickness of 20 mm. The resulting optical window had an OH group-content of 200 ppm and a chlorine-content of 10 ppm. In addition, the synthetic quartz glass molded article for an optical window also had an internal transmittance as determined at 245 nm of not less than 99%. The synthetic quartz glass molded article for optical windows was irradiated with light from a KrF laser under the same conditions used in Example 1 to determine the changes in absorbance at 248 nm. The results obtained are shown in FIG. 2 together with the results obtained in Example 1. The sample of Comparative Example 1 exhibits an increase in the absorbance at 215 nm unlike the sample of Example 1. This indicates that the synthetic quartz glass molded article for optical window does not have stability sufficient for use as an optical member for excimer lasers.

Comparative Example 2

A porous synthetic silica deposit produced in the same manner used in Example 1 was heat-treated in an atmospheric furnace maintained at 800°C for 5 hours while supplying a 1:9 mixed gas of chlorine and nitrogen at a flow rate of 10 l/min, followed by withdrawing the porous synthetic silica, introducing it into a vacuum furnace in which it was heated to 1600°C at a vacuum of 1 x 10^{-2} Torr for one hour and then cooling to give a transparent rod-like synthetic quartz glass material. The resulting synthetic quartz glass material was molded and annealed in the same manner used in Example 1 to give a sample for analysis and a synthetic quartz glass molded article for an optical window having an outer diameter of 80 mm and a thickness of 20 mm.

The resulting synthetic quartz glass molded article for an optical window had an OH group-content of 1 ppm and a chlorine-content of 400 ppm. In addition, the synthetic quartz glass molded article for an optical window had an internal transmittance as determined at 245 nm of 94.7%. The transmittance curve, in the ultraviolet region, observed for the synthetic quartz glass molded article for optical window is shown in FIG. 5 which shows the appearance of an absorption band having an absorption center at 245 nm.

The synthetic quartz glass molded article for optical window was irradiated with lights from a KrF laser to determine the changes in absorbance at 215 nm under the same conditions used in Example 1 and the results obtained are shown in FIG. 6 together with the results obtained in Example 1. There was observed an abrupt increase in the absorbance at 248 nm. This indicates that the synthetic quartz glass molded article for optical window does not have stability sufficient for use as an optical member for excimer lasers.

Example 4

After distilling silicon tetrachloride to remove impurities, a cylindrical porous synthetic quartz glass ingot having an outer diameter of 150 mm and a length of 600 mm was produced by the CVD method using the distilled silicon tetrachloride as a starting material. The resulting porous synthetic quartz glass ingot was introduced into a vacuum furnace provided with a carbon heater and the furnace was evacuated to 10^{-5} Torr. Then the porous synthetic quartz glass ingot was heated by operating a heater. The heating operation was carried out according to the following heating program: up to 800°C, at a heating rate of 10°C/min; 800°C to 1400°C, at a heating rate of 1°C/min. Then the heating was interrupted when the temperature reached 1400°C to allow spontaneous cooling of the ingot. Thus, there was obtained a cylindrical transparent synthetic quartz glass material having an outer diameter of 105 mm and a length of 550 mm. The OH group-content of the resulting transparent synthetic quartz glass material was about 25 ppm.

Supporting rods of quartz glass were fitted to both ends of the cylindrical transparent synthetic quartz glass material and fixed to the chucks of a turning machine. The transparent glass portion produced from the porous synthetic quartz glass ingot was heated by a propane gas burner, followed by giving a twist to the transparent glass portion while rotating the turning machine. The temperature during this processing was about 2000°C. The twisted transparent glass portion was free of striae in the three directions.

Thereafter, the transparent glass portion was cut from the ingot, molded in a heating furnace provided

with a carbon heater into cylindrical synthetic quartz glass molded article having an outer diameter of 250 mm and a length of 75 mm. The molding was carried out at about 1700°C in a nitrogen gas atmosphere.

The synthetic quartz glass molded article was then annealed to remove strains. The annealing was performed by raising temperature up to 1100°C and then reducing the temperature down to 600°C at a temperature reduction rate of 0.1°C/min. The heating process was performed in the air. The resulting synthetic quartz glass molded material had a birefringence of not more than 2 nm/cm, a substantially uniform refractive index distribution and a difference between the maximum and minimum of the refractive indices of not more than 1×10^{-6}. Moreover, the concentration of the residual hydrogen molecules present in the synthetic quartz glass material was determined by the Raman scattering method and found to be not more than 1×10^{16} molecules/cm^3.

To examine whether or not the quartz glass molded article forms paramagnetic defects upon irradiation with ultraviolet rays, a part of the transparent quartz glass molded article was cut and the interfacial planes were polished to give a transparent synthetic quartz glass molded article having a size of 10 mm x 10 mm x 40 mm. The synthetic quartz glass molded article was irradiated with the light from an ArF laser to examine changes in the absorbance at 193 nm. The irradiation with the ArF laser was carried out at an energy density of 200 mJ/cm^2.pulse and a frequency of 100 Hz. The intensities of the absorption at 193 nm were plotted on FIG. 7 against the number of irradiated pulses of the ArF laser. The intensity on the ordinate is expressed in terms of absorbance (-log(internal transmittance)) per unit thickness (1 cm) of the sample.

Example 5

After distilling silicon tetrachloride to remove impurities, a cylindrical porous synthetic quartz glass ingot having an outer diameter of 70 mm and a length of 600 mm was produced by the CVD method using the distilled silicon tetrachloride as a starting material. The resulting porous synthetic quartz glass ingot was introduced into a vacuum furnace provided with a carbon heater and the furnace was evacuated to 10^{-5} Torr. Then the ingot was heated by operating a heater. The heating operation was carried out according to the following heating program: up to 800°C, at a heating rate of 10°C/min; 800°C to 1400°C, at a heating rate of 1°C/min. Then the heating was interrupted when the temperature reached 1400°C to allow spontaneous cooling of the ingot. Thus, there was obtained a cylindrical transparent synthetic quartz glass material having an outer diameter of 50 mm and a length of 550 mm. The OH group-content of the resulting transparent synthetic quartz glass material was about 15 ppm.

The cylindrical transparent synthetic quartz glass material was uniformized in the same manner used in Example 4. Thereafter, the transparent glass portion was cut from the ingot, molded in a heating furnace provided with a carbon heater into cylindrical synthetic quartz glass molded article having an outer diameter of 120 mm and a length of 80 mm. The molding was carried out at about 1700°C in a nitrogen gas atmosphere.

The synthetic quartz glass molded article was then annealed to remove strain. The annealing was performed by raising temperature up to 1100°C and then reducing the temperature down to 600°C at a temperature reduction rate of 0.2°C/min. The heating process was performed in the air. The resulting synthetic quartz glass molded material had a birefringence of not more than 2 nm/cm, a substantially uniform refractive index distribution and a difference (Δn) between the maximum and minimum of the refractive indices of not more than 0.8×10^{-6}.

The synthetic quartz glass of this Example was irradiated with the light from an ArF laser to examine changes in the absorbance at 193 nm under the same conditions used in Example 4. The results obtained are summarized and shown in FIG. 7.

Comparative Example 3

A porous synthetic quartz glass ingot produced in the same manner used in Example 4 was introduced into a furnace made of carbon and converted into transparent glass in a He gas atmosphere. The heating operation was carried out by raising the temperature up to 1600°C at a heating rate of 10°C/min, the heating was interrupted when the temperature reached 1600°C to allow spontaneous cooling of the ingot. The OH content of the resulting transparent synthetic quartz glass material was about 300 ppm. Thereafter, the glass material was uniformized, molded and annealed under the same conditions used in Example 1. The birefringence and refractive index distribution thereof were approximately identical to those observed for the synthetic quartz glass prepared in Example 1. The synthetic quartz glass of this Example was irradiated with light from an ArF laser under the same conditions used in Example 4 to determine the change of transmittance at 193 nm. The results obtained are summarized in FIG. 7.

Comparative Example 4

Evaluation of a commonly used synthetic quartz glass molded article for optical use was performed by irradiating it with the light from an ArF laser under the same conditions used in Example 1. This commonly used synthetic quartz glass molded article was one prepared from the synthetic quartz glass synthesized by a direct flame-hydrolysis (direct method using an oxyhydrogen flame) of silicon tetrachloride. The OH content of this glass was about 900 ppm. The glass material was uniformized, molded and annealed under the same conditions used in Example 1. The birefringence and refrac-

tive index distribution thereof were approximately identical to those observed for the synthetic quartz glass prepared in Example 1. In addition, the concentration of hydrogen molecules remaining in the synthetic quartz glass was determined by the Raman scattering method and found to be 3×10^{16} molecules/cm^3. The synthetic quartz glass of this Comparative Example was irradiated with the light from an ArF laser under the same conditions used in Example 4 to determine the change of transmittance at 193 nm. The results obtained are summarized in FIG. 7 together with the results obtained in Examples 4 and 5.

The glass materials prepared in Examples 4 and 5 and Comparative Examples 3 and 4 exhibit approximately the same birefringences and refractive index distributions. Regarding the resistance to irradiation with ArF laser rays as seen from FIG. 7, those of Examples 4 and 5 exhibit increases of absorbance, but the increase in absorbance is substantially suppressed as compared with those observed for Comparative Examples 3 and 4. In particular, the increases in absorbance observed in Examples 4 and 5 are about 1/4 time that observed for Comparative Example 4. This indicates that the optical members of Examples 4 and 5 form only a small number of paramagnetic defects which generate through the irradiation with ArF laser rays and that the vitrification into transparent glass in a vacuum atmosphere can ensure the production of glass stable against the irradiation with excimer laser rays.

The glass materials obtained in these Examples and Comparative Examples except for Comparative Example 4 had a hydrogen molecule concentration of 1×10^{16} molecules/cm^3. The refractive index distribution Δn's were 1×10^{-6} for Example 2, 1×10^{-6} for Comparative Example 1 and 5×10^{-6} for Comparative Example 2. The chlorine-contents were 10 ppm for Examples 4 and 5 and Comparative Example 3 and 80 ppm for Comparative Example 4.

INDUSTRIAL APPLICABILITY

The synthetic quartz glass optical member according to the present invention can be used under a long term irradiation with the light from excimer lasers without causing reduction of light transmittance unlike the conventional synthetic quartz glass optical members. Thus, the optical member of the invention can be used in, for instance, lithography apparatuses for semiconductors over a long time period, this in turn permits a decrease of the number of exchanges of the optical member and stable exposure procedures and this ensures improvement of the semiconductor lithography-efficiency.

Moreover, the synthetic quartz glass optical member for excimer lasers according to the present invention has a refractive index distribution Δn of not more than 1×10^{-6} and, therefore, permits uniform transmission of the light from ultraviolet lasers throughout the optical member under irradiation with lights from excimer lasers, which has never been achieved by the conventional synthetic quartz glass optical members. Accordingly, the optical member allows uniform exposure over a long time period in, for instance, semiconductor lithography apparatuses and ensures improvement of the yield of semiconductor lithography.

The quartz glass optical member for excimer lasers is produced by flame-hydrolyzing a highly pure volatile silicon compound such as highly pure silicon tetrachloride with an oxyhydrogen flame, depositing the fine silica particles formed through the decomposition on a heat-resistant substrate to give a porous ingot of silica glass, heating the porous ingot of silica glass at a high degree of vacuum on the order of 1×10^{-2} Torr to form transparent quartz glass, uniformizing the transparent quartz glass to give highly uniform quartz glass free of striae in at least one direction thereof, molding the highly uniform quartz glass and then annealing the molded article. Therefore, contamination with impurities can substantially be prevented as compared with the conventional quartz glass parts for excimer lasers and the resulting glass has a low density of intrinsic defects. As a result, the present invention makes it possible to suppress the formation of paramagnetic defects during irradiation with the lights from excimer lasers as compared with the conventional methods and can provide quartz glass having excellent resistance to the lights from excimer lasers.

Claims

1. An optical member for excimer lasers made from synthetic quartz glass wherein said optical member has an OH group-content ranging from 10 to 200 ppm, a chlorine-content ranging from 20 to 100 ppm, a hydrogen molecule-content of not more than 1×10^{16} molecules/cm^3, a uniformity of refractive index distribution Δn of not more than 1×10^{-6} wherein Δn is defined as the difference of refractive index in a light-transmissive plane of said optical member between the maximum and minimum refractive indices, a birefringence of not more than 5 nm/cm and an internal transmittance as determined at 245 nm of not less than 99%.

2. An optical member in accordance with claim 1 wherein said synthetic quartz glass is vitrified by heating under a pressure of not more than 1×10^{-2} Torr.

3. An optical member for excimer lasers made from synthetic quartz glass as set forth in claim 1 or 2 wherein the optical member is a window, a mirror, a lens or a prism for excimer lasers having oscillation wave lengths of not more than 300 nm.

4. A method for producing an optical member for ex-

cimer lasers made from synthetic quartz glass wherein said optical member has an OH group-content ranging 10 to 200 ppm, a chlorine content ranging from 20 to 100 ppm, a hydrogen molecule-content of not more than 1 X 10^{16} molecules/cm^3, a uniformity of refractive index distribution Δn of not more than 1 X 10^{-6} wherein Δn is defined as the difference of refractive index in a light-transmissive plane of said optical member between the maximum and minimum refractive indices, a birefringence of not more than 5 nm/cm and an internal transmittance as determined at 245 nm of not less than 99% comprising the steps of:

flame-hydrolyzing a volatile silicon compound using an oxyhydrogen flame to form fine silica particles;
depositing the fine silica particles on a heat-resistant substrate to give a porous silica ingot;
dehydrating and degassifying by heating the porous silica ingot at a temperature of not less than 1400°C and a high degree of vacuum on the order of not less than 1 X 10^{-2} Torr, wherein said dehydrating and degassifying steps occur either sequentially or simultaneously;
uniformizing the dehydrated and degassified transparent quartz glass to give highly uniform quartz glass free of stria in at least on direction thereof;
molding the resulting highly uniform quartz glass; and annealing the molded quartz glass article.

5. A method for producing an optical member for excimer lasers made from synthetic quartz glass as set forth in claim 4 wherein the uniformizing treatment of the quartz glass is carried out at a temperature of not less than 1600°C.

6. A method for producing an optical member for excimer lasers made from synthetic quartz glass as set forth in claim 4 or 5 wherein the molding of the highly uniform quartz glass is carried out at a temperature of not less than 1500°C.

7. A method for producing an optical member for excimer lasers made from synthetic quartz glass as set forth in claim 4, 5 or 6 wherein the annealing is carried out at a temperature ranging from 800 to 1250°C.

Patentansprüche

1. Ein optisches Bauteil für Excimerlaser, welches aus synthetischem Quarzglas hergestellt ist, wobei das optische Bauteil einen OH-Gruppengehalt im Bereich von 10 bis 200 ppm, einen Chlorgehalt im Bereich von 20 bis 100 ppm, einen Wasserstoffmolekül-Gehalt von nicht mehr als 1 x 10^{16} Moleküle/cm^3, eine Gleichförmigkeit der Brechungsindexverteilung Δn von nicht mehr als 1 x 10^{-6}, wobei Δn als die Differenz des Brechungsindex in einer lichtdurchlässigen Ebene des optischen Bauteils zwischen dem maximalen und dem minimalen Brechungsindex definiert ist, eine Doppelbrechung von nicht mehr als 5 nm/cm und eine innere Durchlässigkeit von, wenn bei 245 nm bestimmt, nicht weniger als 99 % aufweist.

2. Ein optisches Bauteil nach Anspruch 1, wobei das synthetische Quarzglas durch Erwärmen unter einem Druck von nicht mehr als 1 x 10^{-2} Torr verglast wird.

3. Ein optisches Bauteil für Excimerlaser, welches aus synthetischem Quarzglas hergestellt ist, wie in Anspruch 1 oder 2 dargelegt, wobei das optische Bauteil ein Fenster, ein Spiegel, eine Linse oder ein Prisma für Excimerlaser mit Oszillationswellenlängen von nicht mehr als 300 nm ist.

4. Ein Verfahren zum Produzieren eines optischen Bauteils für Excimerlaser, welches aus synthetischem Quarzglas hergestellt wird, wobei das optische Bauteil einen OH-Gruppengehalt im Bereich von 10 bis 200 ppm, einen Chlorgehalt im Bereich von 20 bis 100 ppm, einen Wasserstoffmolekül-Gehalt von nicht mehr als 1 x 10^{16} Moleküle/cm^3, eine Gleichförmigkeit der Brechungsindexverteilung Δn von nicht mehr als 1 x 10^{-6}, wobei Δn als die Differenz des Brechungsindex in einer lichtdurchlässigen Ebene des optischen Bauteils zwischen dem maximalen und dem minimalen Brechungsindex definiert ist, eine Doppelbrechung von nicht mehr als 5 nm/cm und eine innere Durchlässigkeit von, wenn bei 245 nm bestimmt, nicht weniger als 99 % aufweist, mit den Schritten der Flammenhydrolyse einer flüchtigen Siliziumverbindung unter Verwendung einer Knallgasflamme, um feine Siliziumdioxidteilchen zu bilden,

des Ablagerns der feinen Siliziumdioxidteilchen auf einem wärmeresistenten Substrat, um einen porösen Siliziumdioxid-Block zu ergeben,
des Entwässerns und Entgasens durch Erwärmen des porösen Siliziumdioxid-Blocks bei einer Temperatur von nicht weniger als 1400°C und einem hohen Vakuumgrad in der Größenordnung von nicht weniger als 1 x 10^{-2} Torr, wobei die Entwässerungs- und Entgasungsschritte entweder sequentiell oder gleichzeitig stattfinden,
des Vereinheitlichens des entwässerten und entgasten transparenten Quarzglases, um ein

hochgradig gleichförmiges Quarzglas frei von Schlieren in wenigstens einer seiner Richtungen zu ergeben,
des Formens des resultierenden hochgradig gleichförmigen Quarzglases, und
des Temperns des geformten Quarzglasgegenstandes.

5. Ein Verfahren zum Produzieren eines optischen Bauteils für Excimerlaser, welches aus synthetischem Quarzglas hergestellt wird, wie in Anspruch 4 dargelegt, worin die vereinheitlichende Behandlung des Quarzglases bei einer Temperatur von nicht weniger als 1600°C ausgeführt wird.

6. Ein Verfahren zum Produzieren eines optischen Bauteils für Excimerlaser, welches aus synthetischem Quarzglas hergestellt wird, wie in Anspruch 4 oder 5 dargelegt, worin das Formen des hochgradig gleichförmigen Quarzglases bei einer Temperatur von nicht weniger als 1500°C ausgeführt wird.

7. Ein Verfahren zum Produzieren eines optischen Bauteils für Excimerlaser, welches aus synthetischem Quarzglas hergestellt wird, wie in Anspruch 4, 5 oder 6 dargelegt, worin das Tempern bei einer Temperatur im Bereich von 800 bis 1250°C ausgeführt wird.

Revendications

1. Elément optique formé d'un verre de quartz synthétique pour lasers à excimère, ledit élément optique ayant une teneur en groupes OH comprise entre 10 et 200 ppm, une teneur en chlore comprise entre 20 et 100 ppm, une teneur en molécules d'hydrogène ne dépassant pas 1 x 10^{16} molécules/cm^3, une distribution homogène de l'indice de réfraction, Δn, ne dépassant pas 1 x 10^{-6}, où Δn est défini comme la différence d'indice de réfraction dans un plan de transmission de la lumière dudit élément optique, entre l'indice de réfraction maximal et l'indice de réfraction minimal, une biréfringence ne dépassant pas 5 nm/cm, et un coefficient de transmission interne d'au moins 99 %, déterminé à 245 nm.

2. Elément optique selon la revendication 1, dans lequel ledit verre de quartz synthétique est vitrifié par chauffage à une pression d'au plus 1 x 10^{-2} torr.

3. Elément optique formé d'un verre de quartz synthétique pour lasers à excimère selon la revendication 1 ou 2, ledit élément optique étant une fenêtre, un miroir, une lentille ou un prisme pour lasers à excimère ayant des longueurs d'onde d'oscillation ne dépassant pas 300 nm.

4. Procédé de fabrication d'un élément optique formé d'un verre de quartz synthétique pour lasers à excimère, dans lequel ledit élément optique a une teneur en groupes OH comprise entre 10 et 200 ppm, une teneur en chlore comprise entre 20 et 100 ppm, une teneur en molécules d'hydrogène ne dépassant pas 1 x 10^{16}molécules/cm^3, une distribution homogène de l'indice de réfraction, Δn, ne dépassant pas 1 x 10^{-6}, où Δn est défini comme la différence d'indice de réfraction dans un plan de transmission de la lumière dudit élément optique, entre l'indice de réfraction maximal et l'indice de réfraction minimal, une biréfringence ne dépassant pas 5 nm/cm, et un coefficient de transmission interne d'au moins 99 %, déterminé à 245 nm, comprenant les étapes consistant à :

hydrolyser à la flamme un composé silicié volatil en utilisant une flamme oxhydrique pour former des particules fines de silice ;
déposer les particules fines de silice sur un substrat résistant à la chaleur, de façon à obtenir un lingot de silice poreuse ;
effectuer une déshydratation et un dégazage en chauffant le lingot de silice poreuse à une température d'au moins 1 400°C et sous un vide poussé de l'ordre d'au moins 1 x 10^{-2} torr, lesdites étapes de déshydratation et de dégazage se déroulant successivement ou simultanément ;
homogénéiser le verre de quartz transparent déshydraté et dégazé de façon à obtenir un verre de quartz très homogène exempt de stries au moins dans une direction ;
mouler le verre de quartz très homogène résultant ; et
recuire l'article moulé en verre de quartz.

5. Procédé de fabrication d'un élément optique formé d'un verre de quartz synthétique pour lasers à excimère selon la revendication 4, dans lequel on effectue le traitement d'homogénéisation du verre de quartz à une température d'au moins 1 600°C.

6. Procédé de fabrication d'un élément optique formé d'un verre de quartz synthétique pour lasers à excimère selon la revendication 4 ou 5, dans lequel on effectue le moulage du verre de quartz très homogène à une température d'au moins 1 500°C.

7. Procédé de fabrication d'un élément optique formé d'un verre de quartz synthétique pour lasers à excimère selon la revendication 4, 5 ou 6, dans lequel on effectue le recuit à une température comprise entre 800 et 1 250°C.

FIG.1

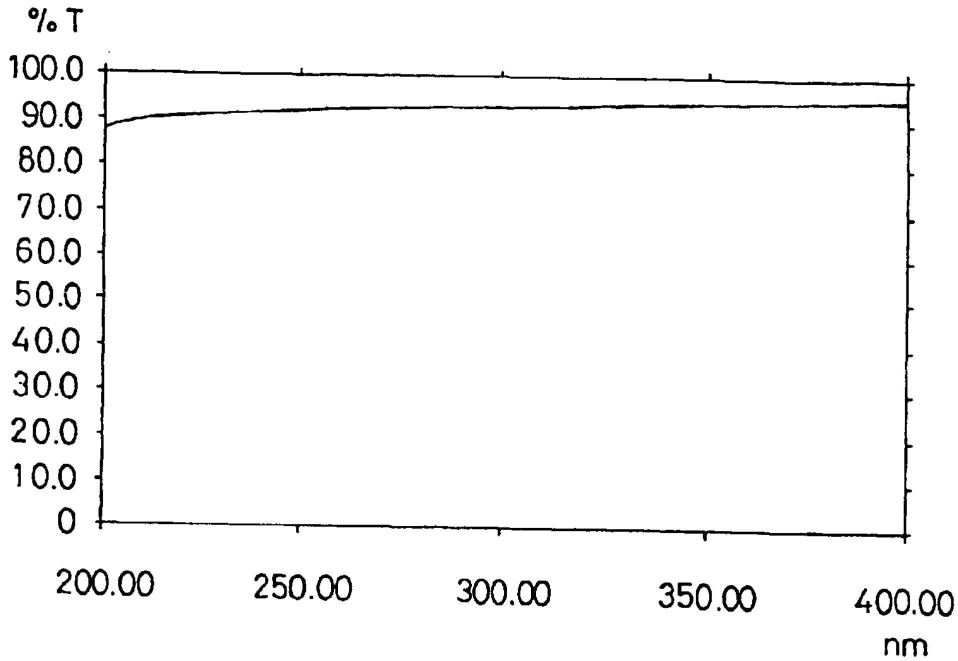

%T
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
200.00
250.00
300.00
350.00
400.00
nm

FIG.2

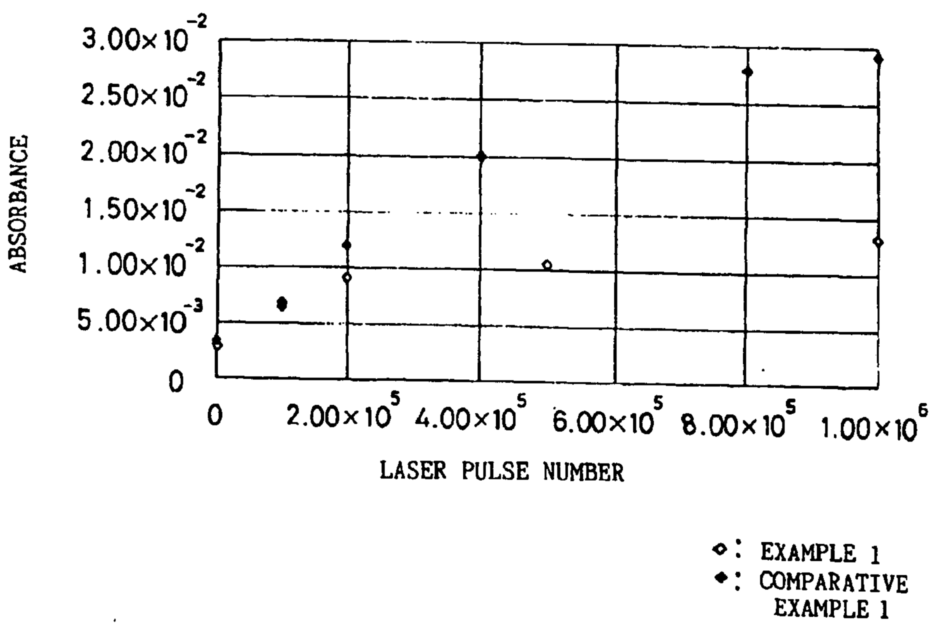

ABSORBANCE
3.00×10^-2
2.50×10^-2
2.00×10^-2
1.50×10^-2
1.00×10^-2
5.00×10^-3
0
0
2.00×10^5
4.00×10^5
6.00×10^5
8.00×10^5
1.00×10^6
LASER PULSE NUMBER
◇: EXAMPLE 1
◆: COMPARATIVE EXAMPLE 1

FIG.3

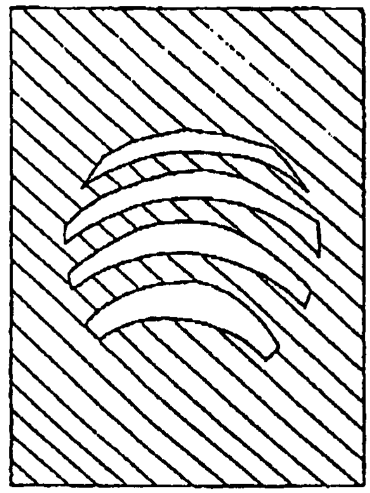


FIG.4

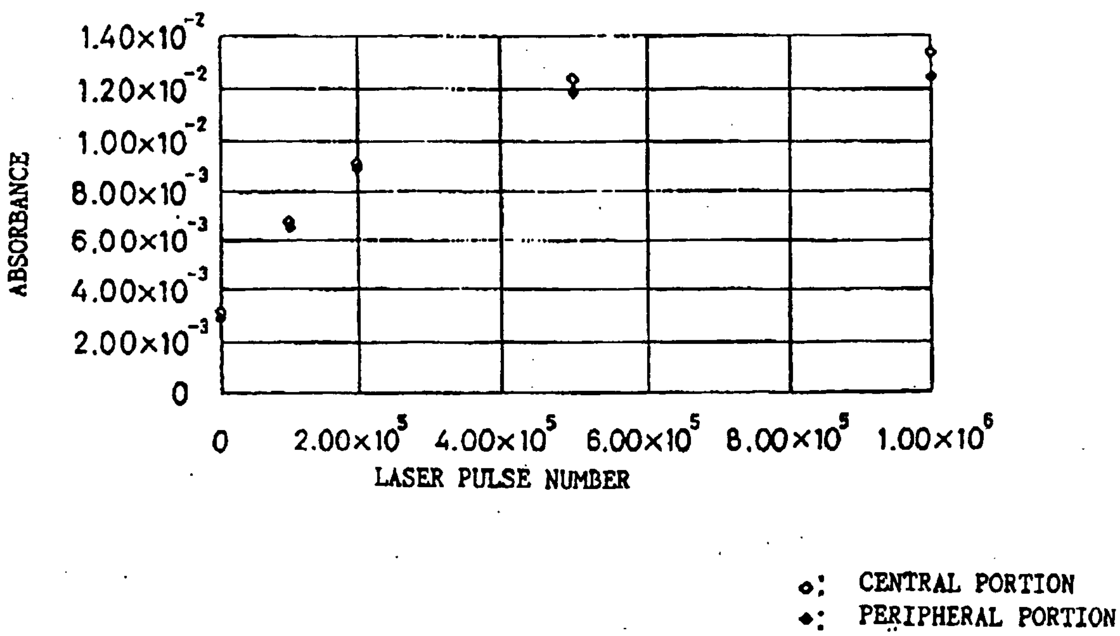

ABSORBANCE
1.40×10^{-2}
1.20×10^{-2}
1.00×10^{-2}
8.00×10^{-3}
6.00×10^{-3}
4.00×10^{-3}
2.00×10^{-3}
0
0
2.00×10^{5}
4.00×10^{5}
6.00×10^{5}
8.00×10^{5}
1.00×10^{6}
LASER PULSE NUMBER
o: CENTRAL PORTION
•: PERIPHERAL PORTION

FIG.5

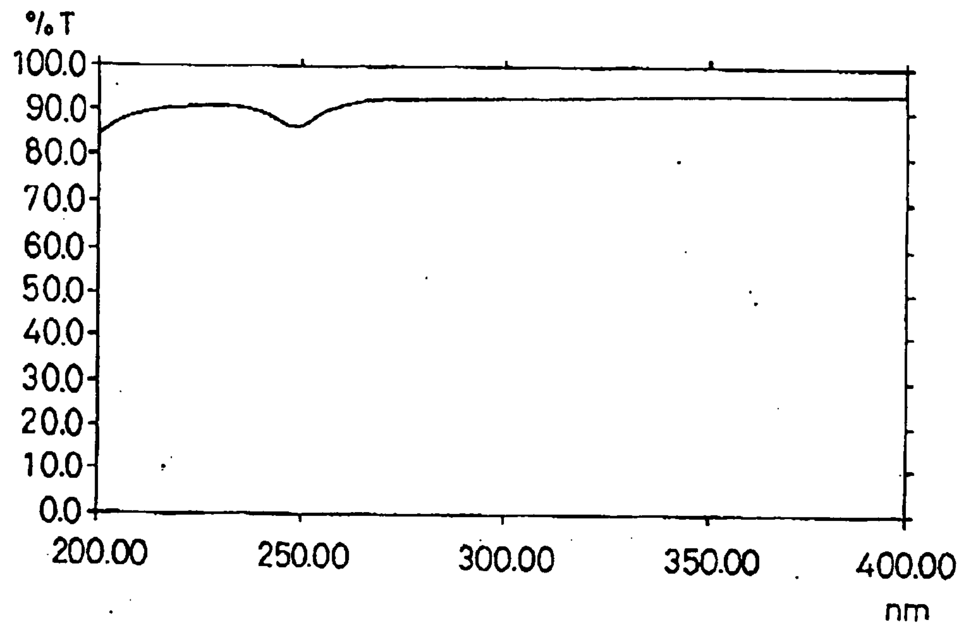

%T
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
200.00
250.00
300.00
350.00
400.00
nm

FIG.6

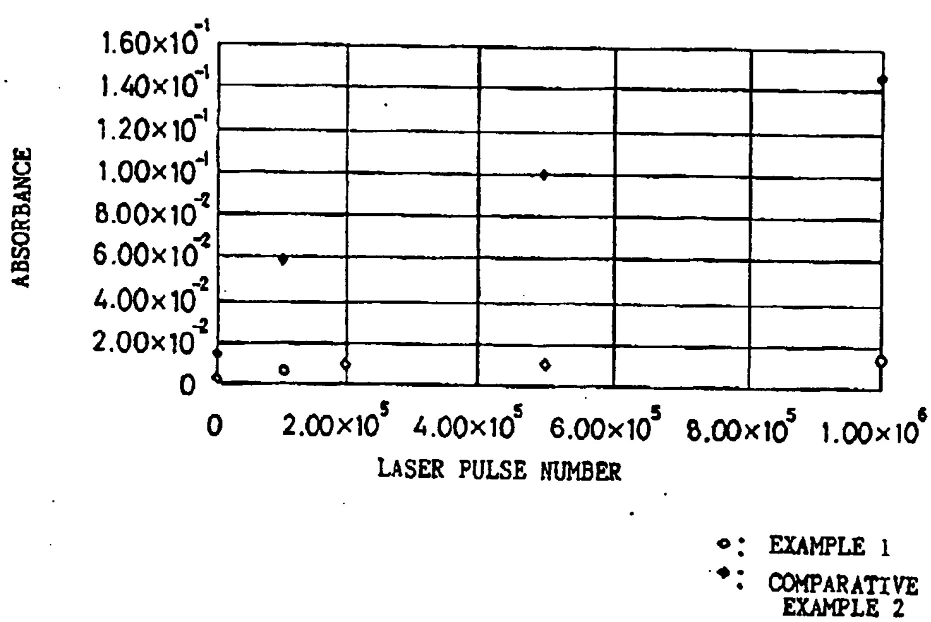
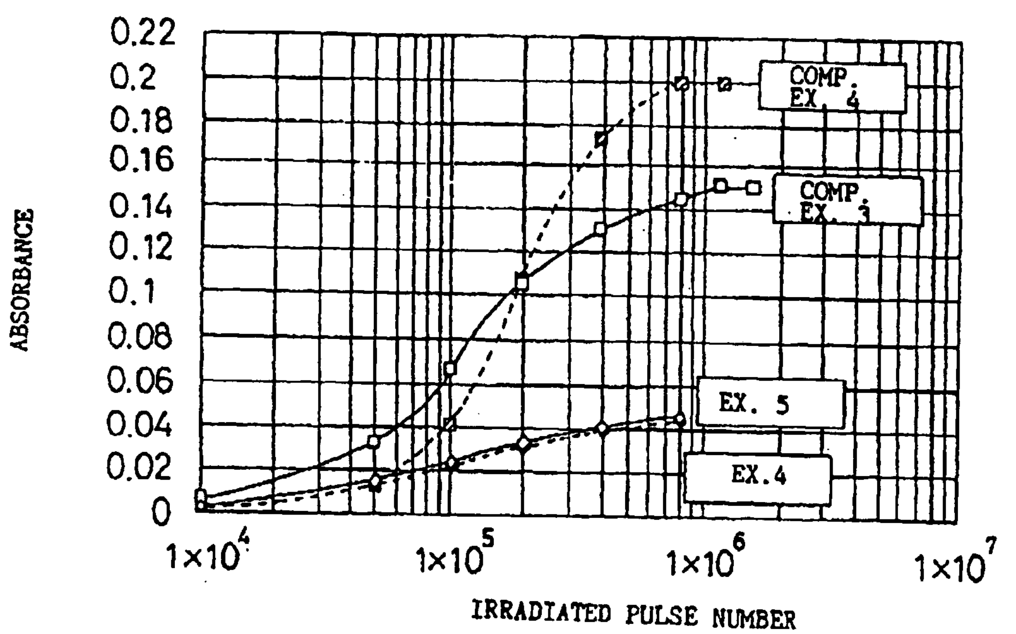

ABSORBANCE
1.60×10⁻¹
1.40×10⁻¹
1.20×10⁻¹
1.00×10⁻¹
8.00×10⁻²
6.00×10⁻²
4.00×10⁻²
2.00×10⁻²
0
0
2.00×10⁵
4.00×10⁵
6.00×10⁵
8.00×10⁵
1.00×10⁶
LASER PULSE NUMBER
○: EXAMPLE 1
◆: COMPARATIVE EXAMPLE 2

FIG.7


0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
ABSORBANCE
COMP. EX. 4
COMP. EX. 3
EX. 5
EX.4
1×10^4
1×10^5
1×10^6
1×10^7
IRRADIATED PULSE NUMBER